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URBAN STORMWATER RUNOFF MITIGATION METHOD USING ARTIFICIAL RECHARGE ON GROUNDWATER

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ABSTRACT

Management of urban storm-water is characterized by the use of hydraulic structures like culvert, man-made channels, water ways, detention basins, infiltration trench, spillway, dams and other drainage structures to either convey or store the storm-water downstream. But in some cases these structures may not be effective to either convey or store the excess runoff because of some inherent factors like topography, soil type, and other factors could include high rain intensity over a long duration and poor drainage design. In the case of Batu Pahat, some of the contributing factors include; flatness of the catchment area, low infiltration rate of the top layer soil (clayey) and ineffectiveness of the hydraulic structure to perform optimally. By adopting the method of injecting some of the storm-water into the ground (aquifer) through a well (perforated pipe), so as to reduce the peak flow rate reaching these structures and also to increase the potential head of the groundwater. It is expected that this will reduce the amount of surface runoff considerably, reduce the amount of polluted storm-water reaching the surface water bodies and also increase the groundwater potential head which will make water available in good quality and quantity for various uses.

Key words: Artificial recharge; storm-water runoff; aquifer; groundwater; flood mitigation

1.0 INTRODUCTION

Over the last decades the world has witnessed a growing number of floods in urban areas (Fig 1.1), which is due to the climate change and rapid urbanization. These floods have lead to lose of millions of lives, destruction of properties, displacement of millions of people and spread of diseases at almost everywhere in the world. Climate change has made flooding a topical issue recently. Places that have never experienced flood are having larger and more devastating storm [4].

Urban flood is highly characterized by the quantity and rate of storm-water runoff, the rate of storm-water runoff is affected by natural surface detention, soil infiltration rate, and the drainage pattern formed by natural flow paths. The soil type, vegetative cover and topography play an important role as well in the resulting quantity of storm water runoff. Urbanization impacts the storm water runoff process in a variety of ways. Infiltration is reduced due to the addition of impervious surfaces, resulting in increasing quantities of run-off. Tree removal, surface leveling, soil flipping and surface compaction are also likely to boost the quantity of runoff. In addition, the rate of storm-water is intensified due to the extensive network of channels that are designed into the urban environment. The increase in runoff quantities and rates can produce downstream flooding and accelerate channel erosion [3].

There have been tremendous progress in the flood mitigation over the years; both new structural and non-structural methods have been applied. But some of these hydraulic structures are not effective enough to mitigate flood, factors contributing to the ineffectiveness could range from topography, soil type to poor design. Droughts are plaguing several countries in the world. In Asia and the Middle East, the hardest hit areas are India, Afghanistan, Iran and Pakistan. Many of these countries in Africa and Asia suffering from water shortage as a result of climate change have massive potential in storm-water harvesting, with nations like Ethiopia and Kenya capable of meeting the need of six to seven times their current population according to a United Nations Report [9].

Fig 1.1: An urban area under massive depth of water.

Fig1.2: Kota Tinggi Town was hit by huge flood in 2007.

2.0 OBJECTIVES AND BACKGROUND OF STUDY

The basic objectives of this research are reduction of peak flow rate and runoff volume by proper and accurate injection of some of the storm-water into an aquifer, increasing the potential head of groundwater which will result as a process of injecting water through an artificial well into an aquifer, and ensuring that the quality of water entering the aquifer is of good quality and desirable for various uses.

Since the late nineteenth century until the mid-twentieth century, storm-water management was usually considered the successful collection and disposal of increased surface runoff. The solution was usually a comprehensive design of roof gutters, downspouts, swales, curbed gutters, sewer inlets, and sewers pipes to collect, convey, and discharge surface runoff to streams, rivers, lakes and other water bodies in the most efficient manner possible. The central theme of storm-water management design was to collect and transport the runoff to nearby body of water as quickly as possible, riddling the developed site of the excess runoff. Little thought was given to the effect of excess runoff and decreased infiltration on the surrounding watershed.

As far back as 1886, a severe flood with gale-force winds caused extensive damages to Kelantan, Malaysia. The flood of 1926, supposedly the worst in living memory of Malaysia, affected most of the Peninsular Malaysia, resulting in extensive damages to property, road systems and agricultural land and crops. In 1967, disastrous flood surged across the Kelantan, Terengganu and Perak river basins, taking 55 lives. A few years later, in 1971, a catastrophic flood swept across many parts of the country. Flood occurred at Kota Tinggi at the end of 2006 and at the beginning of 2007 (Fig 1.2). Flood seem to be getting more frequent in recent years especially in some cities like Kuala Lumpur, Penang and Kuching where rapid urbanization is taking place [1].

. There are two main channels i.e., Parit Karjo and Parit Botak which end at the Straits of Malacca. Commonly, the land surface is flat and low and only 1 to 2 m above the main sea level and the top soil is dominated by soft clay and peat soils. For a long time ago, during rainy season this area was always flooded by averaging 0.5 m water depth and average rainfall intensity of 2,400 mm/year. To overcome this problem, two reservoirs were provided, one at Sembrong River completed in 1984 with capacity of 14 million m^3 and another one at Bekok River completed in 1990 with capacity of 33.7 million m^3 used to store rain water during rainy season for flood control and managing the outflow during dry season for providing water supply. After the both reservoirs developed, the area of Batu Pahat was free from flood. Unfortunately, this safe condition was broken by the occurrence of two consecutive floods, one was on December 19, 2006 and the latest one was on January 12, 2007 [1].

This is a typical example of a situation where the constructed hydraulic structure fails to perform effectively as intended. Like mentioned earlier this could be as a result of factors ranging from topography, soil type, poor design to very high rainfall intensity. This research is intended to proffer a way to reduce the peak flow rate reaching these already constructed hydraulic structures, by injecting some of the storm-water into the ground (aquifer) with the use of artificial recharge. It is aimed that with this the potential head of water in the ground will increase and also the peak flow rate and the dept of runoff reaching this structures will be considerably reduced. This will not only make these expensive structures still useful but it will surely elongate their lifespan and protect them from damage.

2.1 METHODOLOGY

The methodology of the research can be divided into three main parts:

2.1.1 SELECTION OF STUDY AREA

A 25 ha of study area of flat clay which is planned in the field laboratory of RECESS, UTHM has been selected as the study area. The determination of subsurface land profile of the study area using resistivity study to obtain the availability of confined aquifer will be carried out the equipments ABEM Tetrameter SAS 4000.

2.1.2 CONSTRUCTION OF WELLS

Construction of recharge well (perforated pipe) that connects groundwater and surface water, construction of surface water runoff intake (PVC water tank equipped with discharge measurement) and construction of production and monitoring wells (perforated pipe) that produces groundwater. The equipment will be drilling machine and the materials will be gravel, bentonite and PVC pipe. These are the necessary wells to be constructed for the research.

2.1.3 DATA COLLECTION (IN TERMS OF WATER QAUNTITY)

Data collection will be done by Implementation of pumping test to obtain parameters of aquifer such as storage coefficient and water drawdown (the equipments are submersible pump and water checker), data collection of injecting water from intake well. This is will be read with the aid of a flow meter, data collection of production well by pumping water from the aquifer to surface land, data collection of storm water and data collection of water quality.

2.1.4 DATA COLLECTION (IN TERMS OF WATER QUALITY)

Data of interest in terms of water quality are BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), TDS (Total Dissolved Solids), TS (Total Solid), equipment to test for these parameters is the DR 5000. Parameters like Nitrate (NO□), Nitrite(NO3), Phosphorus(PO4), Iron(Fe), Manganese(Mn) and Aluminum (Al) will be measured with the aid of DR 4000. And also the turbidity, conductivity, salinity pH and temperature will be measured using pH meter. The above parameters will be measured before and after injection water into the well.

3. 0 RAINWATER COLLECTION (RAIN HARVESTING)

Collecting of rainwater for use during dry months in rain barrel or other depositories is an ancient and traditional practice. With the use of a suitable rain collection system, large amount of rainwater can be harvested directly from the roof and directed towards an artificial recharge well [7].

Among the equipment needed to collect and also measure the flow rate of surface runoff are; drain collector, water tank, PVC pipes and flow rate meter. And a water checker will be used to carry out a simple water quality test.

The amount of water that can be collected during an average rainfall of 1 inch depth on a household with roof area (40ft by 50ft) is calculated as the following.

It has been established that for every inch of rain that falls on a catchment area of 1000 ft^2 you can expect to collect approximately 600 gallon of rainwater. Ten inches of rain falling on a 1000ft^2 will generate about 6000 gallon. Using the dimension of a theoretical household having roof area of 40ft by 50ft (including eaves), the average amount of rainfall that can be collected can be calculated as thus:

40ft X 50ft = 2000 ft^2

From the above expression that,

1 in = 600 gallons of water for a 1000 ft^2 and our theoretical house has a 2000 ft^2 catchment area.

So we multiply 600 gal X 2 = 1200 gal.

If there is an average rainfall of say 20 inches per year, then the potential to collect

24,000 gallons of water in one year is very feasible.

1200 gallon X 20 in of rain = 24,000 gal.

It should be therefore noted that rainwater harvesting systems aren't necessarily 100% efficient. Most sources estimate efficiency between 70% and 90%.

3.1 ESTIMATING PEAK FLOW AND RUNOFF DEPTH

For any type of storm-water management design, estimates of surface runoff are important. For this research it is important to give values to the peak flow and runoff depth before and after the installation of the system. This will give precise and accurate values to the efficiency of the system. If the peak flow and runoff depth are known before the installation of the system then this can be compared with the values of the peak flow and runoff depth after the installation [2].

The Natural Resources Conservation Service (NRCS) can be a good equation to be used for this purpose.

$$Q\,\frac{\left[P-\left(200/CN\right)+2\right]}{\left[P+\left(800/CN\right)-8\right]} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where: Q = runoff depth (in)
P = Precipitation (in)
CN = curve number

The total volume can be calculated using

$$V = Q \times A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: V = volume of runoff
A = drainage area

3.2 ARTIFICIAL RECHARGE ON GROUNDWATER

Ways by which aquifers can be recharged are; using spreading basins, abandoned streams channels and wells. The dynamic process of the mechanism of recharge through injection wells are governed by the groundwater governing equation and are thus discussed as follows [3];

The governing equation for groundwater flow is

$$Ss\left(x\right)\frac{\left[\partial h\left(x,t\right)\right]}{\partial t} = \nabla\left[k\left(x\right)\nabla h\left(x,t\right) \pm qs\left(x,t\right)\right]x \notin \Omega \quad \ldots\ldots\ldots\ldots (3)$$

Subject to initial condition

$$H\left(x,0\right) = h^{0}\left(x\right)x \notin \Omega$$

And the generalized boundary condition

$$K\left(x\right)\nabla h\left(x,t\right)n = \left[H - h\left(x,t\right)\right] + Qx \notin \Gamma \ldots (4)$$

Where: x = position vector
$H(x, t)$ = hydraulic head as function of position conductivity [L]
$K(x)$ = hydraulic conductivity [L/T]
Ω = flow domain of the aquifer
$Sx\ (x)$ = specific storage [L] -1
Γ= domain boundary
$Qs\ (x, t)$ = internal sink/source term [L^3/T]
t = time
n = unit vector normal to Γ pointing out of the aquifer
H = prescribed boundary head [L]
Q = prescribed boundary flux [L/T]
α = parameter controlling the type of boundary condition

Water spreading has been used in the Western United states for decades to capture additional runoff. Currently, use of injection wells to recharge the groundwater systems has become as accepted method of slowing or stopping overdrafts of groundwater. In water short area, surface water may be captured in basins during spring runoff, and allowed to recharge groundwater later in the year by one of several water-spreading methods. Elsewhere, treated surface water is stored underground until needed later in the season during peak demand periods. If the intent of a management program is to recharge a confined aquifer, then recharge wells must be used.

The design of a well for artificial recharge is similar to that of a supply well. The principal difference is that water flows out of the recharge well into the surrounding aquifer under either a gravity head or a head maintained by an injection pump. The same theoretical consideration applies to wells that extract water and those that inject water. During well pumping, drawdown of the head in the aquifer around the well occurs, during injection there is an increase in the head in the aquifer. From a mathematical standpoint, injection is handled by using a negative value for the pumping rate. A pumping cone, or cone of depression, will form in the aquifer around a pumping well as the water level declines [3].

3.3 Determining Aquifer Parameters

3.3.1 From the time Draw-down data

In an aquifer test a well is pumped and the rate of decline of the water level in nearby observation wells is noted. The time-draw-downs are then interpreted to yield the hydraulic parameters of the aquifer. In conducting an aquifer test, there must obviously be a pumping well. There are usually one or more observation wells [6].

3.3.2 Steady- state conditions

If a well pumps long enough, the water level may reach a state of equilibrium; that is, there is no further draw-downs with time. The region around the pumping well where the head has been lowered is known as a cone depression. When equilibrium has been achieved, the cone depression stops growing because it has reached a recharge boundary. These are also known as steady-state conditions [3].

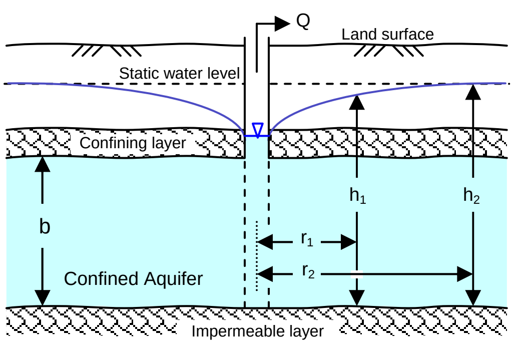

Fig 1.2 Steady radial flow in a confined aquifer

The figure above shows a well penetrating a confined aquifer under steady state conditions the rate that water is pumped from the well is equal to the rate that the aquifer transmits water to the well (G. Theim 1906).

From Darcy's law the flow of water through a circular section of the aquifer toward the well is the area of the circular section 2πrb, times the hydraulic conductivity times the hydraulic gradient

$$Q = (2\pi rb)K\left(\frac{dh}{dr}\right) \qquad \text{………………… (5)}$$

Where: Q = pumping rate (L^3/T)
r = radial distance from the circular section to the well (L)
b = aquifer thickness (L)
K = hydraulic conductivity (L/T)
dh/dr = hydraulic gradient (dimensionless)

Since Transmisivity is the product of aquifer thickness and the hydraulic conductivity the equation 1.4 can also be expressed as

$$Q = (2\pi rb)T\left(\frac{dh}{dr}\right) \qquad \text{………………… (6)}$$

Rearranging

$$dh = \frac{Q}{2\pi\, t}\frac{dr}{r} \qquad \text{.................................... (7)}$$

If there are two observation wells, the head is h1, at a distance r1, from the pumping well; it is h2 at a distance r2

By integrating both side

$$\int_{h_1}^{h_2} dh = \frac{Q}{2\pi T}\int_{r_1}^{r_2}\frac{dr}{r}$$

it will yield

$$h_2 - h_1 = \frac{Q}{2\pi T}\ln(r_2/r_1)$$

Rearranging again will give

$$T = \frac{Q}{2\pi T}(h_2 - h_1)\ln(r_2/r_1)$$

Where:

T = aquifer transmisivity (L^2/ T; ft^2 or m^2/day)
Q = pumping rate (L^3/T; ft^3/day or m^3/day)
$h1$= head at distance $r1$ from pumping well (L; ft or m)
$h2$ = head at distance $r2$ from pumping well (L; ft or m)

If rw is the radius of the well and R is the radius of influence of the well, then the drawdown at the well (Sw) is

$$Sw = H - hw = \frac{Q}{2\pi T}\ln\left(\frac{R}{rw}\right) \qquad (8)$$

4.0 RESULT AND DISCUSSION

The result expected by injecting some of the storm-water into the ground with the use of artificial recharge well can be evaluated when there is a considerable reduction in the runoff peak flow rate and runoff volume. The efficiency of system proposed is greatly dependent on how much is injected into the ground.

It is expected that the amount of peak flow rate is reduced and the amount of runoff volume is as well reduced. This will greatly be dependent on the amount of rainwater collected from the roof and the possibility and ease of injecting this water into the ground. It is also expected that the potential head of the groundwater will increase. This will be observed by the use of an observation well constructed in the area of study. Other aquifer parameter like transmisivity, storage coefficient and drawdown will also be observed. The quality of the water is expected to be of good quality. The system will provide for a mechanism by which the rainwater will be drained directly from the roof without any contact with the ground as it is directed into the recharge well. This will ensure that the water is free from contaminants. A schematic diagram of the model of the research is shown in appendix I.

4.1 ACKNOWLEDGEMENT

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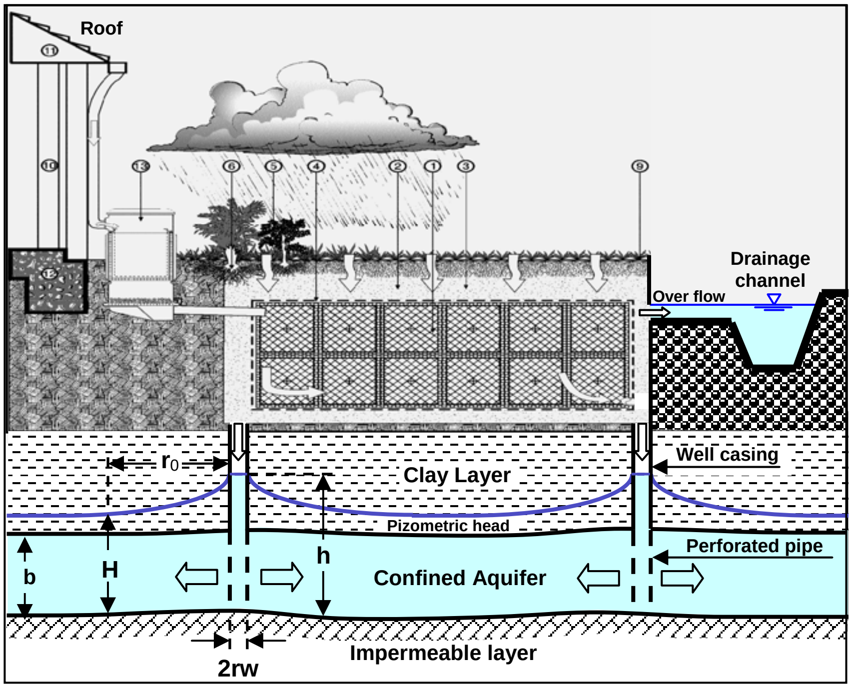
4.2 REFERENCE

[1] Adila, N.A. And Tjahjanto, D., (2008). ***Study on Type and Infiltration Rate of Top Soil in Campus of UTHM***. .
[2] Akan A. O, Houghtalen, R. J (2003). ***Urban Hydrology, Hydraulics and Stormwater Quality*** p. 166-170
[3] Saybert, T. A (2006) ***Storm water Management.*** P 179-191.
[4] Szollosi-Nagy & Zevenberge, C (2005): ***Urban Flood Management.*** P 1-4.
[5] Water Well Journal, (1983). ***Recharge RecoveryIntroduced in Southwest Florida Community***. Volume 37,No 7, p.13.
[6] Wurbs, R. A, James W. P (2002) ***Water resources Engineering.*** p. 223-228 p. 558-560.
[7] www.rainbarrelguide.com
[8] www.un.org

APPENDIX I



Drain system using artificial recharge well (perforated pipe) on groundwater